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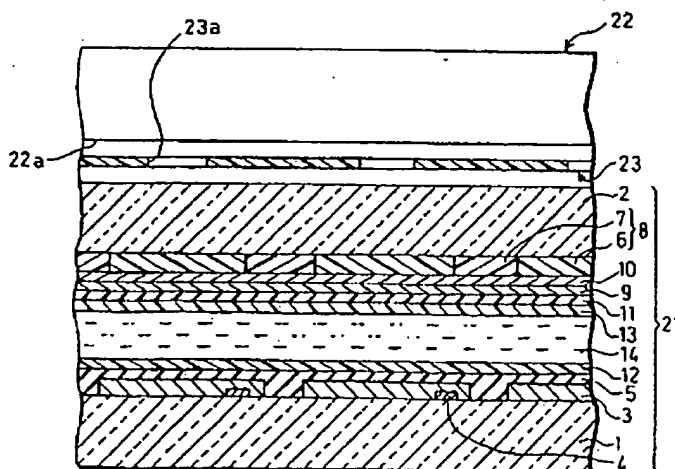
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(54) Abstract Title

Liquid crystal display device

(57) A liquid crystal display device performs display by controlling transmittance of light from a back-light unit 22 by switching each pixel between two or more display states. When performing display, angles of inclination of longitudinal axes of liquid crystal molecules with respect to surfaces of a pair of glass substrates 1 and 2 holding a liquid crystal layer 14 therebetween are approximately the same in the respective display states. A slit plate 23 is also provided, which, among the light from the back-light unit 22, only allows transmission of light having an angle of incidence, with respect to a normal direction of the glass substrate 2, of no more than a predetermined angle. By means of this structure, brightness during black state is greatly decreased in comparison with a cell not provided with the slit plate 23, and contrast ratio is improved. As a result, a liquid crystal display device can be provided which shows high contrast, and is not influenced by scattering of light due to, for example, a colour filter.

FIG. 1



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FIG. 1

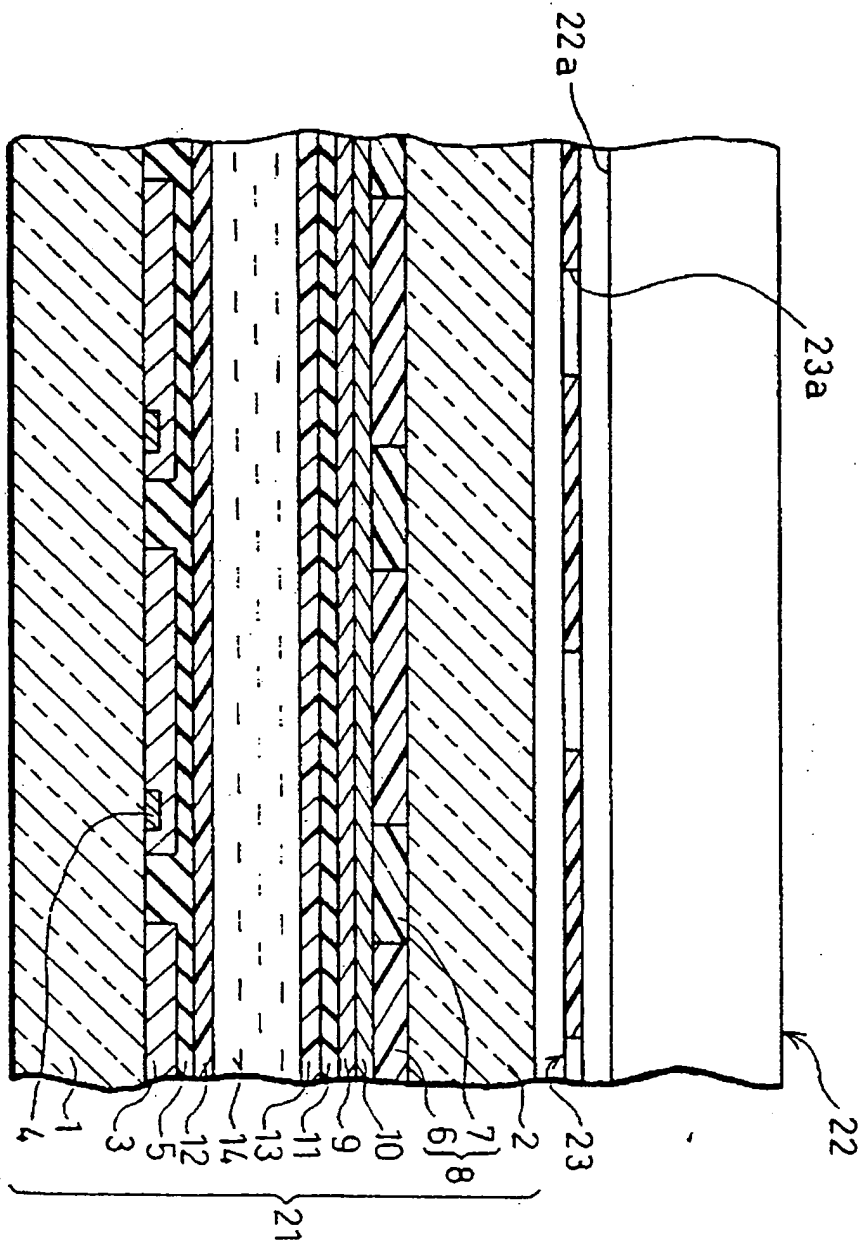


FIG. 2

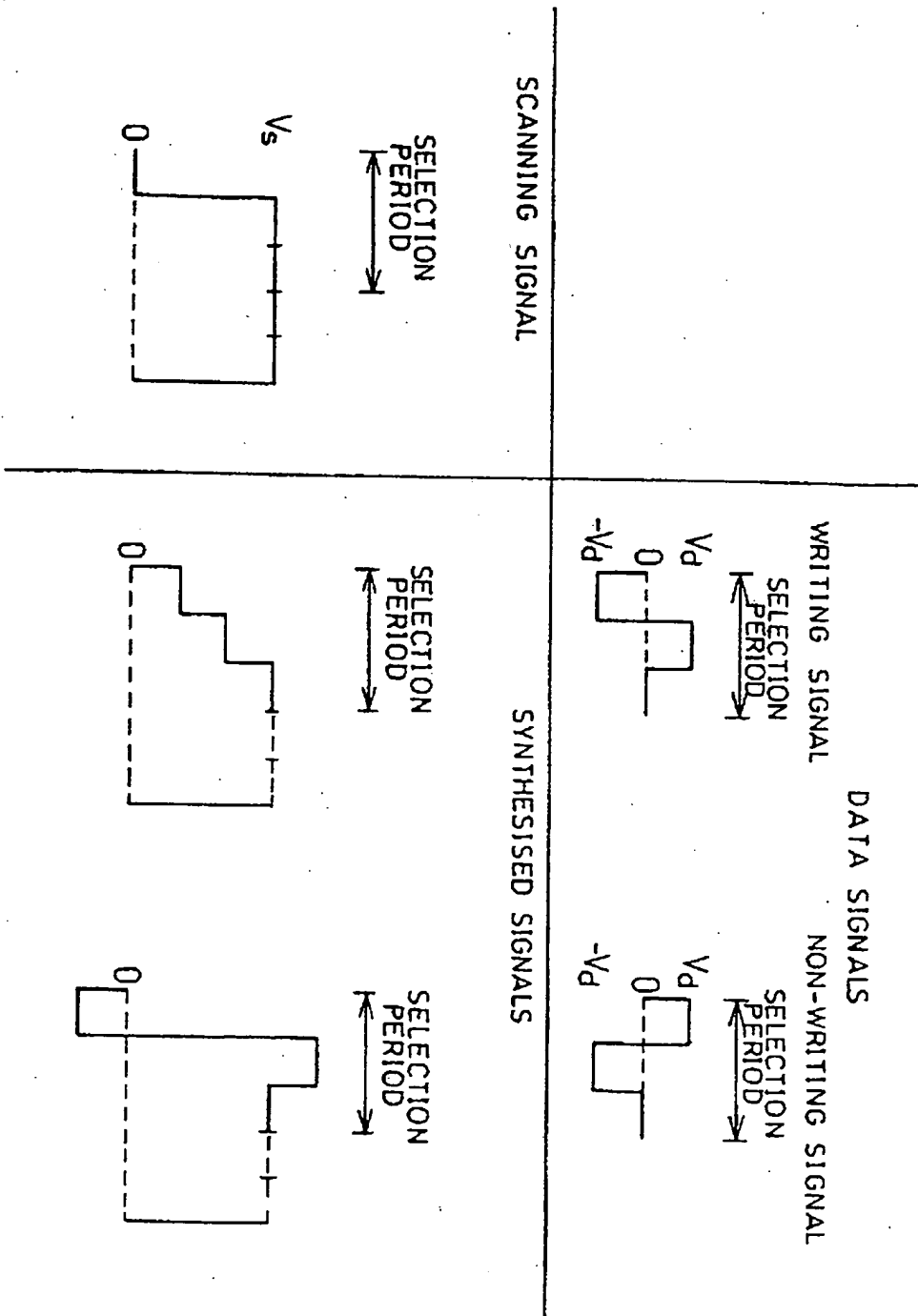
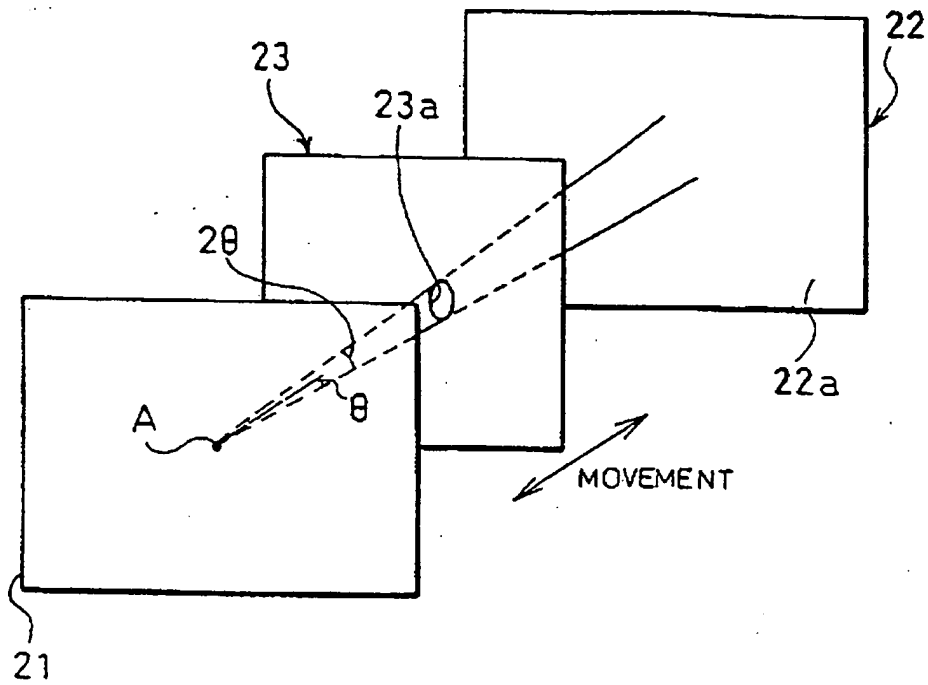


FIG. 3



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FIG. 4

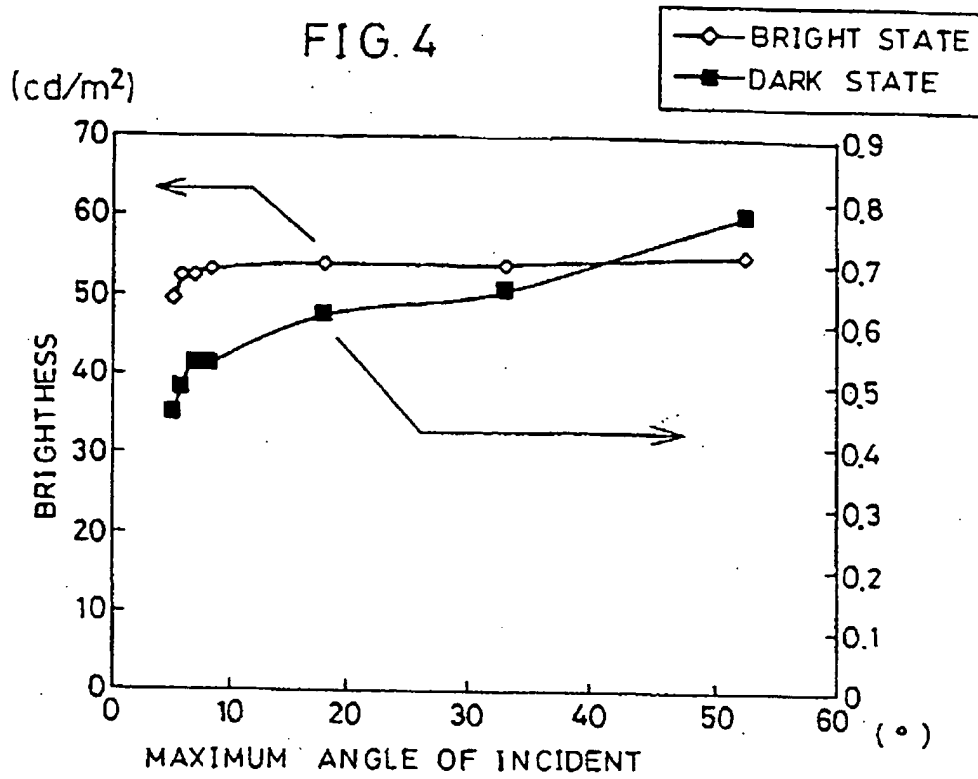


FIG. 5

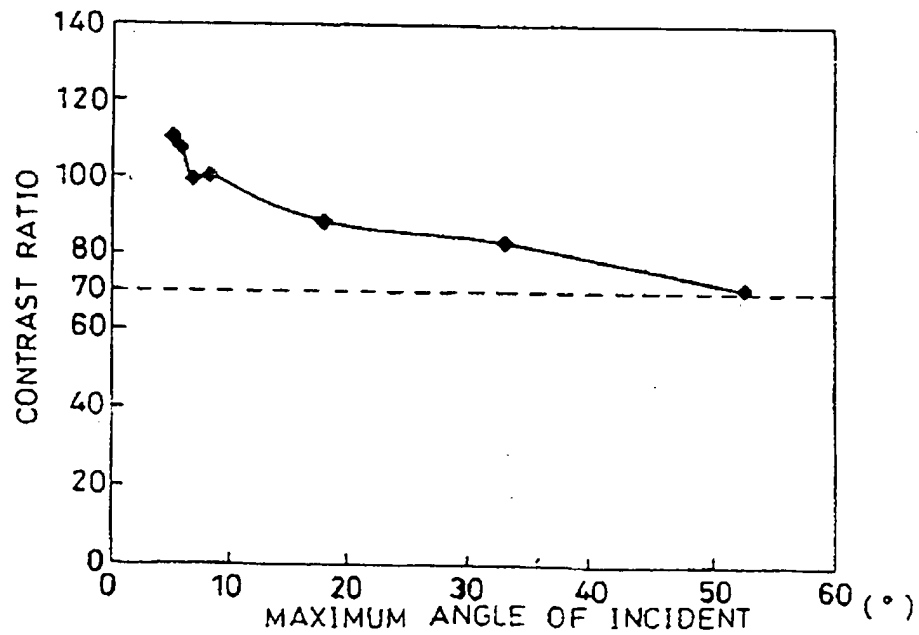


FIG. 6

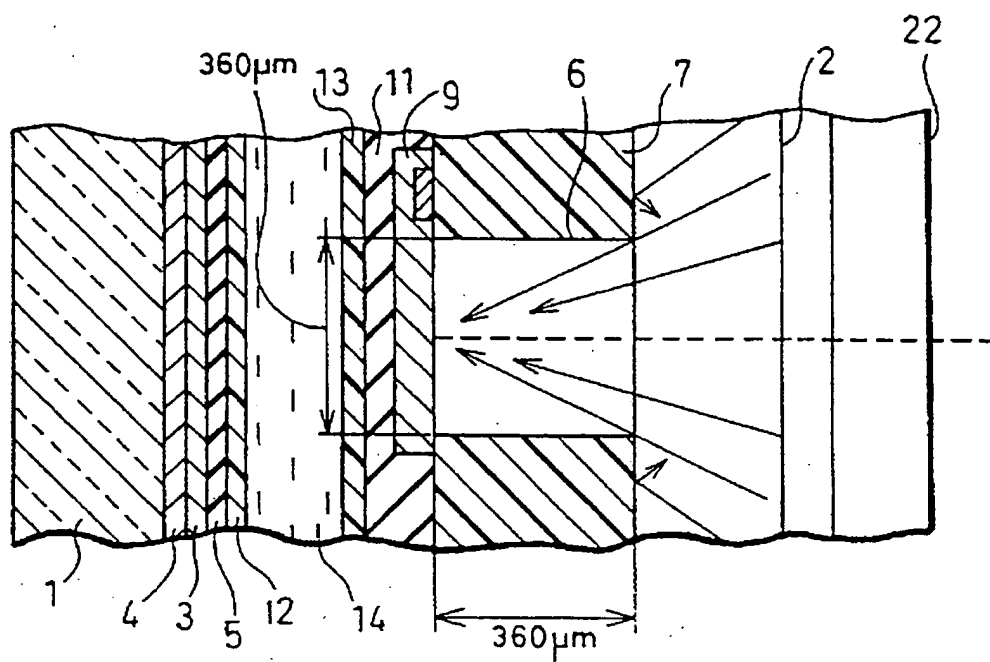


FIG. 7

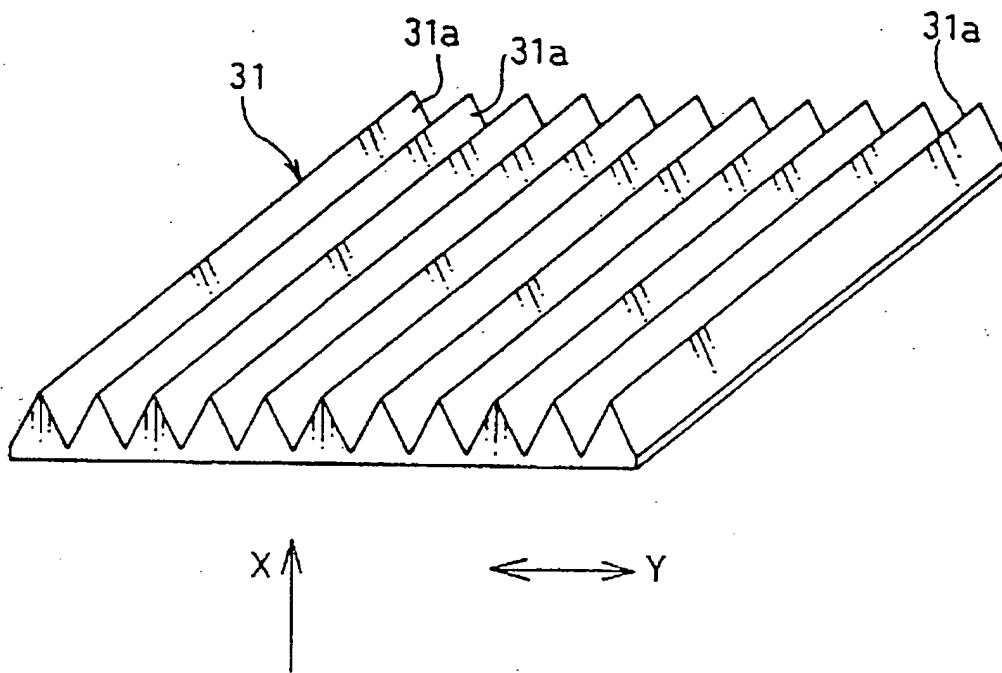
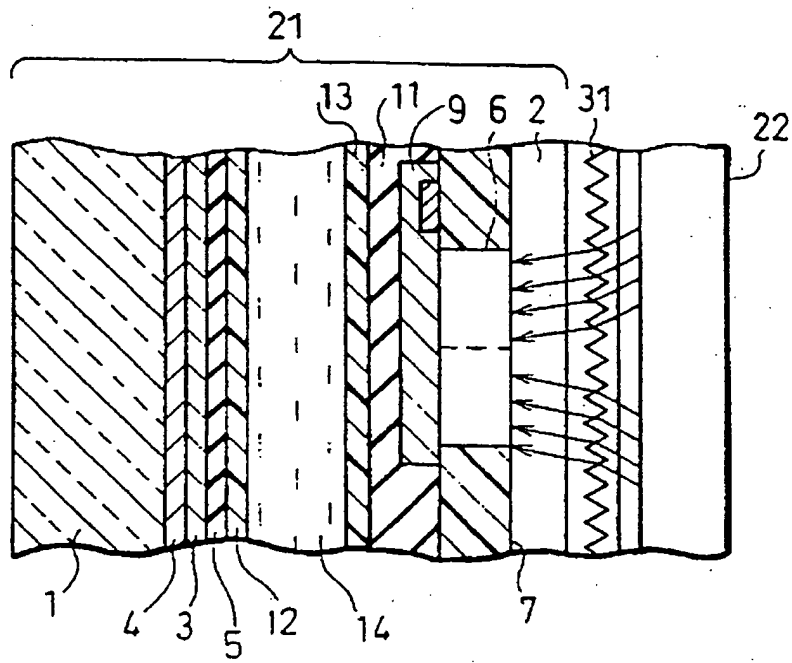


FIG. 8



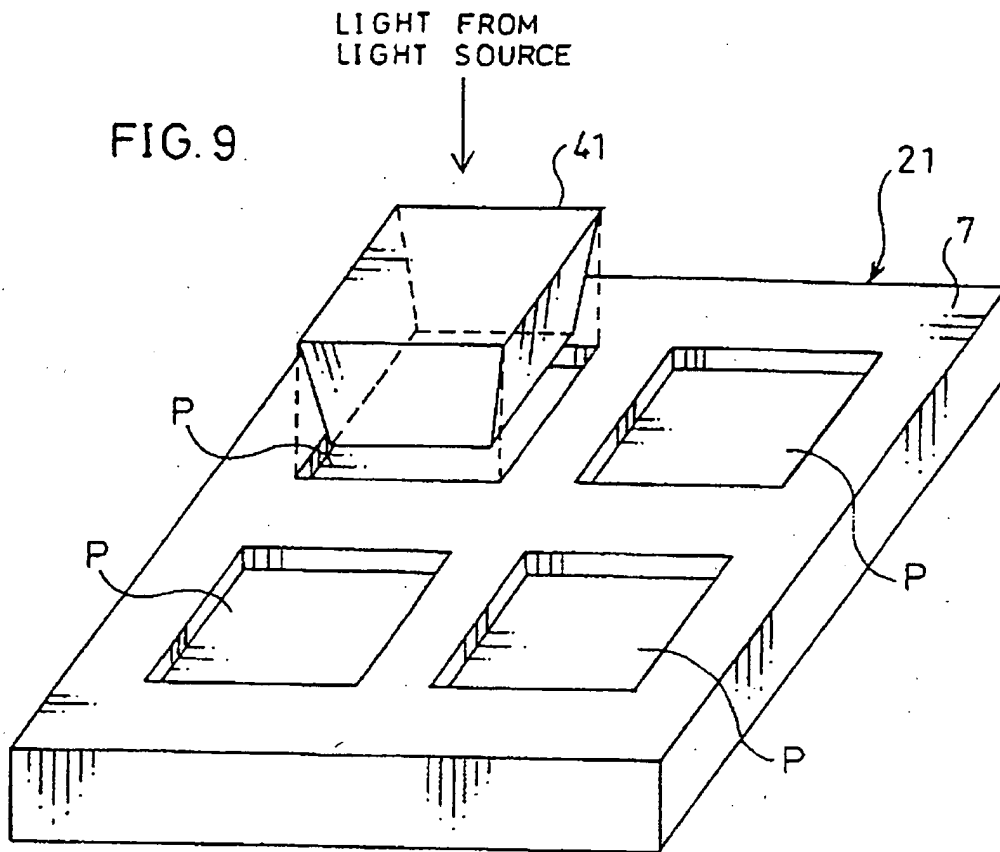
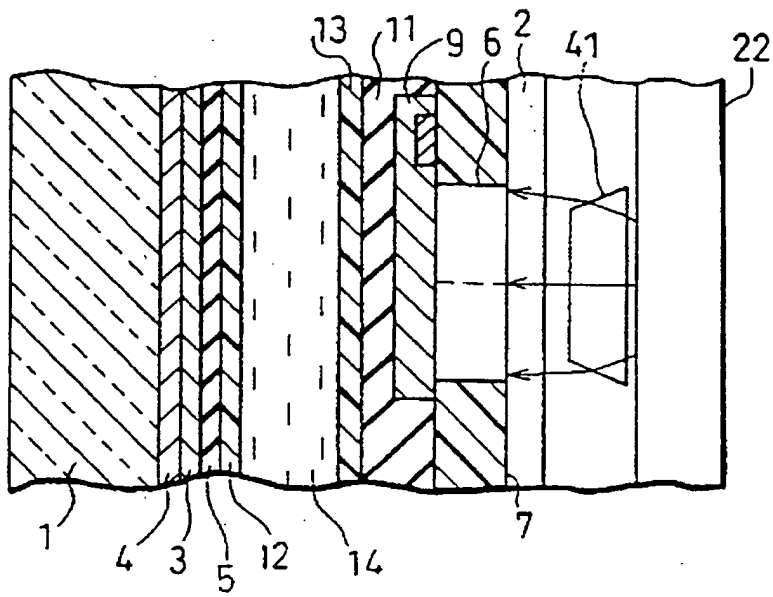


FIG.10



## LIQUID CRYSTAL DISPLAY DEVICE

The present invention relates to a liquid crystal display device which provides display of high quality by improving contrast.

In thin-film transistor (TFT) liquid crystal display devices, which are one type of liquid crystal display device, each of a plurality of pixels making up the display surface is provided with a thin-film transistor, and these thin-film transistors control the state of switching of the liquid crystal. Generally, row electrodes are scanned one by one, thus opening the gates of the thin-film transistors provided in the pixels belonging to that row electrode, and a peak value of a voltage applied to the source (or drain) of each thin-film transistor at that time controls the switching state (grey level) of that pixel. Presently, research and development are actively pursuing realisation of large screen size, said to be difficult with this type of active matrix liquid crystal display device.

Meanwhile, much interest has been shown in ferroelectric liquid crystal display devices, which, due to the memory ability (bistability) of the ferroelectric liquid crystal itself, can realise high-quality display

in a so-called simple matrix (passive matrix) structure, without providing active elements such as transistors. Switching of the display state of ferroelectric liquid crystal is performed while maintaining the liquid crystal molecules in an alignment which is parallel to the pair of substrates holding the liquid crystal layer therebetween. For this reason, ferroelectric liquid crystal display devices have excellent viewing field angle characteristics, because good contrast ratio (a ratio between brightness during white state and brightness during black state) can be obtained, not only for a viewing angle directly in front of the screen, but also for inclined viewing angles.

In the present Specification, "viewing angle" will mean the angle, with respect to the normal direction of the surface of the liquid crystal display device, from which the viewer views the liquid crystal display device. Further, "viewing field angle" will mean the maximum value of viewing angle at which a predetermined contrast ratio can be obtained.

In practically applying ferroelectric liquid crystal display devices, it is important to realise, in a simple matrix structure, display of a quality as good as or better than that possible with an active matrix structure, and particularly important to obtain a high

contrast ratio. Therefore, in order to obtain a high contrast ratio, conventional research has pursued successive improvement of the liquid crystal material, liquid crystal alignment techniques, liquid crystal driving methods, etc.

Active matrix liquid crystal display devices conventionally use TN (Twisted Nematic) liquid crystal, and adopt a driving method in which a voltage is applied in a direction perpendicular to the substrates which hold the liquid crystal layer therebetween. When no voltage is applied, the liquid crystal molecules as a whole have a twisted arrangement, but each liquid crystal molecule is substantially parallel to the substrates. When voltage is increased to change the display state, the liquid crystal molecules begin to tilt toward the direction of application of the voltage (perpendicular to the substrates). In other words, in accordance with the display state, the angle of inclination of the liquid crystal molecules with respect to the surface of the substrate changes. In this way, with switching which involves change of the angle of inclination of the liquid crystal molecules, viewing angle dependence arises, in which a high contrast ratio cannot be obtained for some viewing angles.

For this reason, in order to reduce viewing angle

dependence, in-plane switching liquid crystal has been introduced in active matrix liquid crystal display devices as well. When causing nematic liquid crystal to function as in-plane switching liquid crystal, switching is performed while maintaining the alignment of the liquid crystal substantially parallel to the substrates holding the liquid crystal layer therebetween, and thus excellent viewing field angle characteristics can be obtained.

However, in liquid crystal display devices, a high contrast ratio can be obtained in comparatively small test cells, but when the foregoing technique for improving viewing field angle characteristics is applied to a large-size panel in order to try for practical application, it is sometimes impossible to reproduce the high contrast ratio obtained with the test cell. This is due to, for example, the fact that good alignment can be obtained fairly easily in a comparatively small test cell, and the fact that the structure of the test cell and that of the large-size panel differ greatly.

For example, with a ferroelectric liquid crystal display device, when increasing panel size, it is customary to provide a colour filter for colour display, and to provide metal wires along with the transparent electrodes (made of, for example, ITO) in order to

minimise dulling of the voltage applied to the liquid crystal which accompanies increase in the line resistance of the transparent electrodes. The colour filter and metal wires are a cause of scattering of light. Accordingly, a large-size panel may be prone to loss of contrast ratio, which was not marked in the small test panel not provided with these members.

It is an object of the present invention to provide a liquid crystal display device showing high contrast ratio.

According to the present invention, there is provided a liquid crystal display device which controls transmittance of light from a light source by switching each pixel between two or more display states, such that angles of inclination of longitudinal axes of liquid crystal molecules with respect to surfaces of a pair of substrates holding a liquid crystal layer therebetween are approximately the same during the respective display states; the liquid crystal display device including incident light limiting means which, among the light from the light source, only allow transmission of light having an angle of incidence, with respect to a normal direction of the substrates, of no more than a predetermined angle.

Further, according to the present invention, there

is also provided a liquid crystal display device including a liquid crystal layer including ferroelectric liquid crystal; a pair of substrates parallel to each other, which hold the liquid crystal layer therebetween; a light source, which emits light toward the substrates; and a plurality of pixels; further provided with light limiting means, which, among the light from the light source, only allow light having an angle of incidence, with respect to a normal direction of the substrates, of no more than a predetermined angle to enter the liquid crystal layer.

Further, according to the present invention, there is also provided a liquid crystal display device including a liquid crystal layer containing liquid crystal molecules; a pair of substrates parallel to each other, which hold the liquid crystal layer therebetween; a light source, which emits light toward the substrates; and a plurality of pixels; the liquid crystal display device being an in-plane switching liquid crystal display device, performing switching among a plurality of display states by changing an orientation of longitudinal axes of the liquid crystal molecules while maintaining the longitudinal axes parallel to the substrates; and the liquid crystal display device being further provided with light limiting means, which, among the light from the

light source, only allow light having an angle of incidence, with respect to a normal direction of the substrates, of no more than a predetermined angle to enter the liquid crystal layer.

With each of the foregoing structures, since the respective angles of inclination of the longitudinal axes of the liquid crystal molecules with respect to the substrate surface are approximately the same during the respective display states, the optical characteristics of the liquid crystal do not change even if the display surface is viewed from different angles (in other words, viewing field angle is wide). By providing incident light limiting means in this type of liquid crystal display device having a wide viewing field angle, light having an angle of incidence of no more than a predetermined angle is transmitted, but light having an angle of incidence exceeding the predetermined angle is blocked. Consequently, brightness during dark state is greatly decreased, and as a result, contrast ratio is greatly improved directly in front of the display surface. This is especially marked in large-size liquid crystal display devices. Accordingly, a liquid crystal display device with good display quality can be provided.

As discussed above, in large-size liquid crystal display devices, the colour filter and the metal wires

provided along with the transparent electrodes cause scattering of light, but light having a high angle of incidence, which causes scattering of light, is blocked by the incident light limiting means. Consequently, scattering of light is suppressed, and contrast ratio is improved.

Japanese Unexamined Patent Publication Nos. 61-284731/1986 (Tokukaisho 61-284731, published December 15, 1986) and 4-9818/1992 (Tokukaihei 4-9818, published January 14, 1992) disclose techniques which seek to improve display quality by allowing, among light from a light source, only light having angles of incidence within a certain range to enter the liquid crystal panel, and diffusing light which has passed through the liquid crystal panel (which has been light modulated). These techniques have been applied to liquid crystal display devices with poor viewing field angle characteristics, for performing light modulation using light with a small angle of incidence, which improves contrast ratio, and then diffusing the modulated light in order to improve contrast ratio in directions other than directly in front of the display screen.

Further, Japanese Unexamined Patent Publication No. 1-25123/1989 (Tokukaihei 1-25123, published January 1, 1989) discloses a technique for improving contrast ratio

in a super twisted nematic liquid crystal by limiting incident light from a light source to a range of  $\pm 20^\circ$ . In a cell having super twisted nematic liquid crystal, which is prone to greyscale inversion, this technique seeks to improve display quality by limiting incident light as above, so as not to use light with angles of incidence which cause greyscale inversion.

However, the foregoing conventional techniques have not been applied to liquid crystal display devices having a liquid crystal layer in which, during the respective display states, longitudinal axes of the liquid crystal molecules have substantially the same angle of inclination with respect to surfaces of the pair of substrates holding the liquid crystal layer therebetween.

On the other hand, in liquid crystal display devices having a liquid crystal layer in which, during the respective display states, longitudinal axes of the liquid crystal molecules have substantially the same angle of inclination with respect to surfaces of the pair of substrates holding the liquid crystal layer therebetween, such as in-plane switching liquid crystal display devices, as discussed above, viewing field angle is large, and greyscale inversion depending on viewing angle does not occur. Further, liquid crystal display devices having a liquid crystal layer in which, during

the respective display states, longitudinal axes of the liquid crystal molecules have substantially the same angle of inclination with respect to surfaces of the pair of substrates holding the liquid crystal layer therebetween, such as a ferroelectric liquid crystal layer, as discussed above, show very good viewing field angle characteristics. For this reason, conventionally, in this type of liquid crystal display device with a large viewing field angle, it was not considered necessary to limit light having large angles of incidence.

However, as a result of assiduous investigation, the present inventors found that, in this type of liquid crystal display device with a large viewing field angle, decrease in contrast ratio occurs directly in front of the display surface.

In answer to the foregoing problem, the present inventors realised that in this type of liquid crystal display device with a large viewing field angle (especially large-size liquid crystal display devices), contrast ratio directly in front of the display surface can be improved by limiting light incident on each pixel to light having a comparatively small angle of incidence.

In the liquid crystal display device structured as above, it is preferable that the liquid crystal layer is

chiefly made up of ferroelectric liquid crystal. Ferroelectric liquid crystal, like the in-plane switching liquid crystal used in active matrix liquid crystal display devices, is a liquid crystal in which the angles of inclination of the longitudinal axes of the liquid crystal molecules with respect to the substrate surface are approximately the same during the respective display states. Consequently, in a liquid crystal display device which uses ferroelectric liquid crystal, just as in one which uses in-plane switching liquid crystal, contrast ratio directly in front of the display surface can be improved. Accordingly, display quality of ferroelectric liquid crystal display devices, especially large-size ferroelectric liquid crystal display devices, can be improved.

It is preferable that the incident light limiting means limit incident light such that contrast ratio (a ratio of brightness during white state to brightness during black state) in a direction perpendicular to the substrates (directly in front of the display surface) is not less than 70. If the contrast ratio is not less than 70, the liquid crystal display device is acceptable for practical use.

As will be discussed below, the present inventors confirmed that in a liquid crystal display device having

a specific structure, a contrast ratio of 70 can be obtained by setting the foregoing predetermined angle at  $50^\circ$ . The predetermined angle with which a contrast ratio of 70 can be obtained apparently varies according to the structure of the liquid crystal display device (width and pitch of the metal wires, for example), and cannot be specified universally. However, if the predetermined angle is set to  $50^\circ$ , light having a comparatively small angle of incidence of  $50^\circ$  or less enters the pixels, and thus, even if the structure of the liquid crystal display device differs slightly from that of the foregoing liquid crystal display devices, influence from the difference in structure will be minimal, and a contrast ratio close to 70 can be obtained. Accordingly, a liquid crystal display device with good display can be provided. Consequently, it is preferable to set the predetermined angle to  $50^\circ$ .

Further, the present inventors confirmed that in the foregoing liquid crystal display device having a specific structure, an even higher contrast ratio can be obtained by setting the predetermined angle to  $10^\circ$ . Consequently, it is more preferable to set the predetermined angle to  $10^\circ$ . In this way, even higher contrast can be obtained. Accordingly, a liquid crystal display device with very good display can be provided.

In the foregoing liquid crystal display device, it

is preferable that light blocking members (such as a black matrix) are provided in regions between the pixels, and that the light blocking members also serve as the foregoing incident light limiting means. If, in this way, the light blocking members generally provided in, for example, colour liquid crystal display devices, are also used as the incident light limiting means, increase in the number of members can be held to a minimum. Accordingly, a liquid crystal display device with good display quality can be provided, while holding to a minimum increase in product cost and complication of the structure.

The present invention will be further described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a cross-sectional view showing the structure of the chief part of a liquid crystal display device according to one embodiment of the present invention;

Figure 2 is a wave-form diagram showing data signals, a scanning signal, and synthesised signals used in evaluating contrast ratio in the foregoing liquid crystal display device applied to a direct-view large-size panel and to a test cell;

Figure 3 is a perspective view showing the structure of a test cell and a direct-view large-size panel provided with a slit plate, used in evaluating contrast ratio;

Figure 4 is a graph showing maximum angle of incidence v brightness characteristics when a slit plate is used;

Figure 5 is a graph showing maximum angle of incidence v contrast ratio characteristics when a slit plate is used;

Figure 6 is a cross-sectional view showing the structure of the chief part of a modification of an embodiment of the present invention;

Figure 7 is a perspective view showing a film for limiting incident light, used in another modification of an embodiment of the present invention;

Figure 8 is a cross-sectional view showing the structure of a liquid crystal display device provided with the foregoing film;

Figure 9 is a perspective view showing light refraction control elements for limiting incident light, used in a further modification of an embodiment of the present invention; and

Figure 10 is a cross-sectional view showing the structure of a liquid crystal display device provided

with the foregoing light refraction control elements.

The following will explain an embodiment of the present invention with reference to Figures 1 through 5.

A liquid crystal display device according to the present embodiment includes a liquid crystal display element (hereinafter referred to as "liquid crystal cell") 21, shown in Figure 1. The liquid crystal cell 21 includes two glass substrates 1 and 2, provided opposite one another. Instead of the glass substrates 1 and 2, transparent substrates made of a resin such as polymethyl methacrylate may be used. Further, to respective outer surfaces of the glass substrates 1 and 2 are affixed polarising plates (not shown), arranged such that polarising axes thereof intersect at right angles with each other.

The surface of the glass substrate 1 which faces the glass substrate 2 is provided with electrodes 3, which are transparent and are made of an electrode material such as ITO (Indium Tin Oxide), and which are provided in the shape of parallel stripes. Further, on the glass substrate 1, along with the electrodes 3, metal wires 4 are provided in the shape of stripes. The metal wires 4 are made of a metal having a lower resistance than the

electrodes 3, and are provided so as to be covered by the electrodes 3. By means of the metal wires 4, the line resistance of the electrodes 3 can be reduced. Further, on the electrodes 3 is layered an insulating layer 5, which is transparent and is made of  $\text{SiO}_2$  (silicon oxide),  $\text{SiN}$  (silicon nitride), etc.

The surface of the glass substrate 2 which faces the glass substrate 1 is provided with a colour filter layer 8, which includes colour filters 6 and a black matrix 7 (light blocking member). The colour filter layer 8 is structured such that red, green, and blue colour filters 6 alternate with the black matrix 7, these members being provided in the same plane and in contact with one another. Further, as needed, the colour filter layer 8 may also be provided with an overcoat film (levelling film) which covers the colour filters 6 and the black matrix 7.

The black matrix is a light-absorbing layer which, in order to prevent light from a back-light unit 22 (to be discussed below) from entering a liquid crystal layer 14 except in pixel domains thereof, cover areas of the liquid crystal layer 14 other than the pixel domains, so as to block light from the back-light unit 22.

On the colour filter layer 8 are provided electrodes 9, which are transparent and are made of, for example,

ITO, and which are provided in the shape of parallel stripes running in a direction at right angles to the electrodes 3. Further, on the colour filter layer 8, metal wires 10 the same as the metal wires 4 are provided in the shape of stripes. The metal wires 10 serve to reduce the line resistance of the electrodes 9. Further, on the electrodes 9 is layered an insulating layer 11, which is transparent and is made of  $\text{SiO}_2$ ,  $\text{SiN}$ , etc.

Further, on the insulating layers 5 and 11 are provided alignment films 12 and 13, which have undergone a uniaxial alignment treatment such as rubbing treatment. As the alignment films 12 and 13, organic polymer films such as polyimide, nylon (polyamide), or polyvinyl alcohol, oblique vapour deposition films of  $\text{SiO}_2$ , etc. may be used. When organic polymer films are used as the alignment films 12 and 13, alignment treatment is usually performed so as to align the liquid crystal molecules substantially parallel to the glass substrates 1 and 2.

The glass substrates 1 and 2 are maintained a predetermined distance apart by means of spacers (not shown), and, using a sealing material (not shown), the peripheries of the glass substrates 1 and 2 are affixed together. Then, by filling the space between the glass substrates 1 and 2 with liquid crystal material, a liquid crystal layer 14 is formed. As the liquid crystal

material, a liquid crystal material such as ferroelectric liquid crystal is used, in which the angles of inclination of the longitudinal axes of the liquid crystal molecules with respect to the substrates are substantially the same in different display states. Because of superior characteristics such as high-speed response, memory ability, etc., ferroelectric liquid crystal is able to display images of large capacity and high resolution.

In the liquid crystal layer 14, ferroelectric liquid crystal molecules (FLC molecules) in the vicinity of the alignment films 12 and 13 incline with respect to the glass substrates 1 and 2 by a certain angle (pre-tilt angle) due to interaction between the alignment films 12 and 13, and FLC molecules in and near the centre of the liquid crystal layer 14 are substantially parallel to the glass substrates 1 and 2. The FLC molecules, subject to a force proportional to a vector product of spontaneous polarisation and an electric field produced by a potential difference between the electrodes 3 and 9, move in an orbit on the surface of a cone, and, since the liquid crystal cell 21 has a small cell gap (around  $1.0\mu\text{m}$  to  $1.5\mu\text{m}$ ), settle into a bistable state. In this bistable state, all of the FLC molecules have approximately the same angle of inclination with respect to the glass

substrates 1 and 2. Consequently, optical characteristics of the liquid crystal layer 14 during the dark and light states are substantially the same regardless of viewing angle, and thus a wide viewing field angle can be obtained.

Further, a pixel domain (not shown) is formed in each area where an electrode 3 is opposite an electrode 9. In each pixel domain, when voltages are applied to the electrodes 3 and the electrodes 9, the state of alignment of the liquid crystal molecules is switched in accordance with the foregoing electrical field produced between the electrodes 3 and the electrodes 9, and thereby display can be performed by changing the display state (light transmittance) between bright (white) state and dark (black) state (and also grey state).

In this way, the liquid crystal cell 21 is made up of the respective layers (films) discussed above. Further, the present liquid crystal display device also includes a back-light unit 22 and a slit plate 23.

The back-light unit 22 (light source) is a planar light source which projects uniform light into a transmission-type liquid crystal display device from the rear thereof. For the back-light unit 22, the edge-light type is often used, but other types are also acceptable. A back-light unit 22 of the edge-light type includes a

fluorescent lamp, a light guiding body, and a reflective plate.

The slit plate 23 (incident light limiting means) is a light blocking plate whose surface is painted black, having a plurality of slits 23a corresponding to the respective pixel domains, and portions thereof other than the slits 23a block light from the back-light unit 22. The slits 23a have the same shape as the pixel domains, and, among light projected by a light emitting surface 22a of the back-light unit 22, only allow passage of light incident on the pixel domains with an angle of incidence not more than a predetermined angle with respect to the normal direction of the glass substrates 1 and 2. For this reason, the slits 23a have a size determined by a relationship between their position relative to the light emitting surface 22a and the pixel domains and the foregoing predetermined angle. Alternatively, when the slits 23a have a predetermined size, the position of the slit plate 23 relative to the light emitting surface and the pixel domains may be adjusted so as to satisfy the conditions of the foregoing predetermined angle.

The following will explain the effect of the slit plate 23 in the liquid crystal display device with the foregoing structure.

First, the following is a comparison of respective contrast ratios of a test cell and of a 17-inch direct-view large-size panel structured as the liquid crystal display device according to the present embodiment, but without the slit plate 23.

The test cell was prepared by providing each of a pair of glass substrates with ITO transparent electrodes, and then successively layering thereon insulating films and alignment films. The size of each portion where the ITO transparent electrodes of the respective glass substrates overlap was approximately 1cm x 1cm. The direct-view large-size panel, on the other hand, being structured as the liquid crystal display device according to the present embodiment, also included colour filters, a black matrix, etc. not provided in the test cell.

In both the test cell and the direct-view large-size panel, the thickness (cell gap) of the liquid crystal layer (the liquid crystal layer 14) was approximately 1.3 $\mu$ m, and a liquid crystal material developed by the present Applicant was used as the ferroelectric liquid crystal material contained in the liquid crystal layer. This liquid crystal material has so-called  $\tau$ -V<sub>min</sub> characteristics, whereby a curve of response speed versus applied voltage characteristics has a minimum value. This liquid crystal material also has negative dielectric

anisotropy. The basic characteristics of this liquid crystal material are shown below. Incidentally,  $\tau_{\min}$  is a minimum pulse width, and  $V_{\min}$  is a voltage at which  $\tau_{\min}$  can be obtained.

Phase transition series (phase transition temperatures in °C):

SmC\*-(68.5)-SmA-(90.7)-N\*-(98.4)-Iso

Spontaneous polarisation (at 25°C): 10nC/cm<sup>2</sup>

Memory angle  $2\theta_m$  (at 25°C): 15.6°

$\tau_{\min}$  (at 25°C): 9 $\mu$ s

$V_{\min}$  (at 25°C): 31V

As the foregoing ferroelectric liquid crystal material, SCE8, available from Merck Co., may be used, or another liquid crystal material having the foregoing characteristics ( $\tau$ - $V_{\min}$  characteristics) may be used.

Applying a three-slot (110) DRAMA driving method (J C Jones and C V Brown, *Proc. of Euro Display '96*, pp. 151-154), the data signals and scanning signals shown in Figure 2 were applied to the test cell and to the direct-view large-size panel. The "110" above indicates that the peak values of data voltage in the first, second, and third slots are  $(-1) \times V_d$  or  $1 \times V_d$ ;  $1 \times V_d$  or  $(-1) \times V_d$ ; and  $0 \times V_d$ , respectively. Accordingly, the data signals comprise a writing signal which is a pulse signal having voltages of  $-V_d$ ,  $V_d$ , and 0 during the first, second, and third slots,

respectively, and a non-writing signal which is a pulse signal having voltages of  $V_d$ ,  $-V_d$ , and 0 during the first, second, and third slots, respectively; the root-mean-square voltage of the data signals is 5V. The scanning signal is a pulse signal with a voltage of 0 in the first slot, and of  $V_s$  (20V) in each of the second through fifth slots; the pulse is lengthened by 2/3 of the selection period, i.e. two slots, to exceed the selection period.

The two synthesised signals shown in Figure 2, obtained by synthesis of the foregoing data signals and scanning signal, are applied to the pixels. Specifically, synthesis of the writing signal and the scanning signal yields the synthesised signal shown on the left in Figure 2, and synthesis of the non-writing signal and the scanning signal yields the synthesised signal shown on the right.

The following will discuss the results of measurement of contrast ratio directly in front of the test cell and the direct-view large-size panel, driven as discussed above.

In the case of the test cell, when brightness of the light emitting surface 22a of the back-light unit 22 was  $6432\text{cd/m}^2$ , brightness was  $8.457\text{cd/m}^2$  during dark state and  $875.3\text{cd/m}^2$  during bright state, thus showing a contrast ratio of 104. In the case of the direct-view large-size

panel, on the other hand, when brightness of the light emitting surface 22a was  $6640\text{cd/m}^2$ , brightness was  $1.103\text{cd/m}^2$  during dark state and  $51.92\text{cd/m}^2$  during bright state, thus showing a contrast ratio of 47.

As shown above, the contrast ratio of the direct-view large-size panel was much lower than that of the test cell. The reason for this great difference in the absolute values of brightness between the test cell and the direct-view large-size panel is that, since the direct-view large-size panel is provided with members which cause scattering of light, such as the colour filters 6 and the black matrix 7, light transmittance during bright display is greatly reduced in comparison with the test cell, which is not provided with these members.

Next, contrast ratio was evaluated for a test cell and a direct-view large-size panel provided with a slit plate 23 between the liquid crystal cell 21 and the back-light unit 22, as shown in Figure 3, for controlling the light incident on the liquid crystal cell 21.

The slit plate 23 used in this evaluation, unlike the fixed type shown in Figure 1, was provided so as to be freely moveable between the liquid crystal cell 21 and the back-light unit 22, so as to adjust by this movement a maximum angle of incidence  $\theta$  of the light from the

back-light unit 22 on a contrast ratio measurement area (hereinafter simply referred to as "measurement area") A of the liquid crystal cell 21, i.e., on a specific pixel domain. As discussed above, the maximum angle of incidence  $\theta$  is an angle with respect to the normal direction of the glass substrates 1 and 2, and is set to  $45^\circ$  here.

The following will discuss the results of measurement of contrast ratio directly in front of the test cell and the direct-view large-size panel, structured as discussed above.

In the case of the test cell, when brightness of the light emitting surface 22a of the back-light unit 22 was  $6432\text{cd/m}^2$ , brightness was  $8.293\text{cd/m}^2$  during dark state and  $879.0\text{cd/m}^2$  during bright state, thus showing a contrast ratio of 106. In the case of the direct-view large-size panel, on the other hand, when brightness of the light-emitting surface 22a was  $6640\text{cd/m}^2$ , brightness was  $0.6128\text{cd/m}^2$  during dark state and  $48.45\text{cd/m}^2$  during bright state, thus showing a contrast ratio of 79.

As shown above, contrast ratio of the direct-view large-size panel provided with the slit plate 23 was much better than that of the direct-view large-size panel not provided with the slit plate 23, and is much closer to the contrast ratio of the test panel. The test panel, on

the other hand, showed good contrast ratio in the first place, and accordingly the slit plate 23 resulted in no great improvement in contrast ratio.

The results of the foregoing evaluation show that contrast ratio can be greatly increased by limiting the light from the back-light unit 22 incident on the measurement area A to light having an angle of incidence of no more than the maximum angle of incidence  $\theta$ . However, it is not preferable to set the maximum angle of incidence  $\theta$  too small, because in this case light is only incident on a small area, and the viewing field angle of the liquid crystal display device is reduced.

The following will discuss the results of measurement of contrast ratio of the direct-view large-size panel when the position of the slit plate 23 was varied from that above. Figure 4 shows a relationship between maximum angle of incidence  $\theta$  on the pixel, calculated from size and position of the slit 23a, and brightness during bright and dark states, and Figure 5 shows a relationship between the maximum angle of incidence  $\theta$  and contrast ratio.

Figure 4 shows that by limiting light incident on the measurement area A to light having an angle of incidence of not more than the maximum angle of incidence  $\theta$ , brightness characteristics can be improved

particularly in the dark state (brightness is reduced). Again, Figure 5 shows that setting the maximum angle of incidence  $\theta$  to  $50^\circ$  can obtain a contrast ratio of 70, better than the contrast ratio of 47 of the direct-view large-size panel not provided with the slit plate 23. A contrast ratio of 70 is a value sufficient for practical use. In particular, it can be seen that when the maximum angle of incidence  $\theta$  is set to  $40^\circ$ , contrast ratio is around 80, yielding a contrast ratio of better than 80% of that of the test cell.

The results of the foregoing evaluation show that contrast ratio can be greatly improved by limiting the light incident on the measurement area A to light having an angle of incidence of no more than the maximum angle of incidence  $\theta$ . Specifically, if the maximum angle of incidence  $\theta$  is set to approximately  $50^\circ$ , contrast ratio can be improved in comparison with a case in which incident light is not limited. In particular, if the maximum angle of incidence  $\theta$  is set to  $10^\circ$ , a contrast ratio of around 100, approximately equal to that in a test cell, can be obtained even in a direct-view large-size panel.

Accordingly, contrast ratio can be improved as much as incident light is limited, but if it is limited too much, viewing field angle characteristics of the liquid

crystal display device may be impaired. In other words, since viewing field angle depends on angle of incidence, an angle of incidence should be set in accordance with the viewing field angle required for the use to which the device is put. For example, a television requires a comparatively wide viewing field angle because viewing by a plurality of viewers is presumed, but a laptop computer allows a comparatively narrow viewing field angle because viewing from directly in front of the screen is presumed.

Further, since angle of incidence depends on the structure of the panel, it may differ if the structure of the panel (the width and pitch of the metal wires, for example) differs. For this reason, if the structure differs from that of the direct-view large-size panel used in the foregoing measurements, the maximum angle of incidence with which a contrast ratio of 70 can be obtained may be expected to differ slightly from  $50^\circ$ . With a comparatively small angle of incidence of  $50^\circ$  or less, the difference attributable to the influence of scattering of light due to, for example, metal wires of different structure can be expected to be fairly small, but in any liquid crystal display device, it is preferable to set the maximum angle of incidence  $\theta$  to an angle with which a practical contrast ratio of 70 can be obtained.

Next, a modification of the foregoing embodiment will be explained with reference to Figure 6.

In a liquid crystal display device according to the present modification, the maximum angle of incidence  $\theta$  (the angle with respect to the normal direction of the glass substrate 2, shown in the Figure as a broken line) is set by controlling the thickness of the black matrix 7, without using a slit plate 23. Specifically, the glass substrate 2 on which the black matrix 7 is formed is provided toward the back-light unit 22. Since the black matrix 7 is a light-absorbing layer, it has the function of limiting light incident on the pixel domain. Accordingly, the thicker the black matrix 7, the more the light incident on the pixel domain is limited. For example, as shown in Figure 6, in a structure in which the thickness of the glass substrate 2 is 1mm, and the size of the pixel domain is  $360\mu\text{m} \times 360\mu\text{m}$ , if the glass substrate 2 is provided with a black matrix 7 having a thickness of  $360\mu\text{m}$ , the black matrix 7 blocks light having angles of incidence of  $45^\circ$  or more. Consequently, light incident on the pixel domain of the liquid crystal layer is limited to light having angles of incidence of less than  $45^\circ$ .

Accordingly, the foregoing contrast ratio of 70 or better (actually, around 80) can be obtained by means of

the black matrix 7 specified above.

The present example uses no incident light limiting means in addition to the liquid crystal cell 21, but uses the black matrix 7 as incident light limiting means. Thus increase of the number of parts and complication of the structure can be prevented.

Next, a further modification of the foregoing embodiment will be explained with reference to Figures 7 and 8.

In order to limit incident light, a liquid crystal display device according to the present modification is provided with a film 31 (a light-limiting film) like that shown in Figures 7 and 8, structured of a plurality of columnar prisms adjoining in a width direction thereof. As the film 31, a light-limiting film available from Sumitomo Chemical Co., for example, is used. The film 31 (incident light limiting means) has a plurality of very small prism-shaped optical refractive elements (hereinafter referred to as "prism-shaped elements") 31a. In the film 31 structured in this way, incident light traveling from a direction X perpendicular to a flat surface of the film 31, having a spread of angles of incidence in two directions (Y directions) perpendicular to triangular grooves formed by the prism-shaped elements

31a, is limited to a smaller spread of exit angles from the film 31 due to optical refraction by the prism-shaped elements 31a.

By providing the film 31 between the liquid crystal cell 21 and the back-light unit 22, as shown in Figure 8, the angles of incidence on the liquid crystal cell 21 (the exit angles from the film 31) are limited. Further, it is also possible to use two films 31, with the respective directions of the triangular grooves substantially perpendicular to each other. With this kind of structure, light having large angles of incidence can be limited, or the quantity of such light transmitted can be reduced to an extent where it causes no problems in actual use. Since the incidence of light is limited by the film 31 in this way, the black matrix 7 may be provided toward the glass substrate 1.

It goes without saying that the film 31 is capable of obtaining the foregoing contrast ratio of 70 or better.

Incidentally, in the film 31, it is preferable that the pitch of the prism-shaped elements 31a be shorter than one side of the pixel domain (which is, for example, 0.3mm).

In the case of the example above, in which the slit plate 23 was used, the structure of the incident light

limiting means is comparatively simple, but since the slit sections and the pixels must be accurately aligned with each other, a certain amount of precision is required when attaching the slit plate 23 to the liquid crystal cell 21.

In the present example, in contrast, not only is the structure of the incident light limiting means comparatively simple, but the precision of attachment of the film 31 to the liquid crystal cell 21 does not become a problem, provided the intervals between the grooves of the film 31 are small enough.

Next, a further modification of the foregoing embodiment will be explained with reference to Figures 9 and 10.

In order to limit incident light, a liquid crystal display device according to the present modification, as shown in Figure 9, is provided with a plurality of light refraction control elements 41, such as a micro-lens array, one for each pixel P. In keeping with the shape of the pixels P, upper and lower surfaces of each light refraction control element 41 (incident light limiting means) are square, and each of the four sides thereof is trapezoidal.

By using elements of this type, as shown in Figure

10, light having large angles of incidence can be limited, or the quantity of such light transmitted can be reduced to an extent where it causes no problems in actual use. Since the incidence of light is limited by the light refraction control elements 41 in this way, the black matrix 7 may be provided toward the glass substrate 1. The light refraction control elements 41 are capable of obtaining the foregoing contrast ratio of 70 or better.

Incidentally, the foregoing embodiment explained an example of a liquid crystal display device in which the liquid crystal layer 14 made of, for example, ferroelectric liquid crystal, is driven by an electric field having a direction perpendicular to the glass substrates 1 and 2. However, the liquid crystal display device according to the present invention may alternatively be an in-plane switching liquid crystal display device in which a liquid crystal layer 14 made of, for example, nematic liquid crystal is driven by an electric field having a direction parallel to the glass substrates 1 and 2. An in-plane switching liquid crystal display device changes the longitudinal direction of the liquid crystal molecules in a plane parallel to the glass substrates by means of an electric field having a

direction parallel to the glass substrates 1 and 2. In this way, light transmittance of the liquid crystal layer 14 is controlled, and switching among a plurality of display states is realized. Incidentally, an electric field having a direction parallel to the glass substrates 1 and 2 may be produced by providing one of the glass substrates 1 or 2 with a pair of comb-shaped electrodes positioned so that their respective teeth alternate, and producing a potential difference between the two comb-shaped electrodes.

CLAIMS:

1. A liquid crystal display device which controls transmittance of light from a light source by switching each pixel between two or more display states, such that angles of inclination of longitudinal axes of liquid crystal molecules with respect to surfaces of a pair of substrates holding a liquid crystal layer therebetween are approximately equal during the respective display states;

said liquid crystal display device including incident light limiting means which, among the light from said light source, only allow transmission of light having an angle of incidence, with respect to a normal direction of said substrates, of no more than a predetermined angle.

2. The liquid crystal display device set forth in claim 1, wherein said liquid crystal layer chiefly comprises ferroelectric liquid crystal.

3. A liquid crystal display device comprising a liquid crystal layer including ferroelectric liquid crystal; a pair of substrates parallel to each other, which hold said liquid crystal layer therebetween; a light source,

which emits light toward said substrates; and a plurality of pixels;

further provided with light limiting means, which, among the light from said light source, only allow light having an angle of incidence, with respect to a normal direction of said substrates, of no more than a predetermined angle to enter said liquid crystal layer.

4. A liquid crystal display device comprising a liquid crystal layer containing liquid crystal molecules; a pair of substrates parallel to each other, which hold said liquid crystal layer therebetween; a light source, which emits light toward said substrates; and a plurality of pixels;

said liquid crystal display device being an in-plane switching liquid crystal display device, performing switching among a plurality of display states by changing an orientation of longitudinal axes of said liquid crystal molecules while maintaining the longitudinal axes parallel to said substrates; and

said liquid crystal display device being further provided with light limiting means, which, among the light from said light source, only allow light having an angle of incidence, with respect to a normal direction of said substrates, of no more than a predetermined angle to

enter said liquid crystal layer.

5. The liquid crystal display device set forth in any one of claim 1 through claim 4, wherein said incident light limiting means limit incident light such that a contrast ratio in a direction perpendicular to said substrates is not less than 70.

6. The liquid crystal display device set forth in any one of claim 1 through claim 4, wherein the predetermined angle is set at 50°.

7. The liquid crystal display device set forth in any one of claim 1 through claim 4, wherein the predetermined angle is set at 10°.

8. The liquid crystal display device set forth in any one of claim 1 through claim 4, further comprising light blocking members, provided in regions between said pixels, which block light from said light source;

said light blocking members also serving as said incident light limiting means.

9. The liquid crystal display device set forth in claim 8, wherein said light blocking members are provided

between one of said pair of substrates and said liquid crystal layer.

10. The liquid crystal display device set forth in any one of claim 1 through claim 4, wherein said incident light limiting means are a light blocking plate having a plurality of slits, provided on the outer side of one of said pair of substrates.

11. The liquid crystal display device set forth in any one of claim 1 through claim 4, wherein said incident light limiting means are a light control film structured of a plurality of columnar prisms adjoining in a width direction thereof.

12. The liquid crystal display device set forth in any one of claim 1 through claim 4, wherein said light limiting means are a plurality of micro-lenses, one provided for each said pixel.



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Claims searched: 1 to 12

Examiner: Geoffrey Pitchman  
Date of search: 12 August 1999

**Patents Act 1977**  
**Search Report under Section 17**

**Databases searched:**

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.Q): G5C (CHX)

Int Cl (Ed.6): G02F 1/1335

Other: ONLINE: EPODOOC WPI JAPIO

**Documents considered to be relevant:**

Category	Identity of document and relevant passage	Relevant to claims
X	EP 0637005 A1 (SEXTANT AVIONIQUE)-see abstract	1-12
P, X,&	US 5877829 (SHARP)- see especially figures 20 and 21	1-12
X	US 4765718 (GENERAL ELECTRIC)-see abstract and column 3 line 28 to column 4 line 18	1-12
X,&	JP 09244018 A (SHARP)-see figure 1 and equivalent US patent 5877829	1-12

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